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A LIMITED FLIGHT AND WIND-TUNNEL INVESTIGATION OF PADDLE SPOILERS AS LATERAL CONTROLS

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SUMMARY

A limited flight and wind-tunnel investigation was conducted to evaluate paddle spoilers as a primary lateral-control system. Preliminary information indicated this type of spoiler might be used in place of flap-type ailerons with the possible advantage of allowing elimination of the power control system or, at the least, of allowing a great reduction in the size and weight of the required power control system. Two spoiler shapes were tested in flight on a jet-powered sweptback-wing airplane at Mach numbers of 0.60 and 0.86 at an altitude of 35,000 feet. Preceding the flight tests, a large number of spoiler shapes were tested on a 1/4-scale half-span wing model in the Langley 300 MPH 7- by 10-foot tunnel at a Mach number of 0.26.

The paddle spoilers were effective at moderate and large deflections but had little or no effectiveness at small deflections. The two spoiler shapes that were tested in flight had overbalanced hinge moments of generally small magnitudes but flight and wind-tunnel data indicate that underbalanced hinge moments can be achieved with suitable shape modifications. The flight and wind-tunnel data on spoiler effectiveness agreed very well; the data on hinge moments agreed in trend but not in absolute magnitude. During the flight tests the pilot commented favorably on the smooth, apparently lag-free rolling response obtained from the spoilers at large deflections and on the lack of sideslip associated with rolling. The overbalanced hinge moments, the lack of effectiveness at small deflections, and the very large control-system friction of 10 to 20 pounds were found to be unacceptable by the pilot. This excessive control-system friction appears to be an inherent fault of paddle-type spoiler control systems and will probably prohibit the use of such spoilers in nonboosted control systems. If some means is found to overcome the ineffectiveness at small deflections, paddle spoilers may be promising for some applications and, if used, may effect a large reduction in the size and weight of the required power control system.

INTRODUCTION

A limited flight and wind-tunnel investigation of a lateral control consisting of paddle-type spoilers has been conducted at the Langley Research Center. For the flight investigation a spoiler installation was incorporated into the 35° sweptback wings of a jet-powered fighter-type airplane. The wind-tunnel investigation was conducted on a half-span wing model in the Langley 300 MPH 7- by 10-foot tunnel.

The object of the program was to develop a lateral-control system which had hinge moments low enough to be operated manually even on high-speed airplanes or, at the least, which could be operated by power control systems of much smaller size and weight than those currently in use. A further requirement was that the control selected should be of a type that could have reasonably good effectiveness characteristics at both transonic and supersonic speeds.

The wind-tunnel investigation was made first and the data obtained served as a guide in the design of the spoiler installation for the airplane. Included in the report are limited data on the paddle-spoiler effectiveness in producing roll and data on the spoiler hinge moments. Comparisons of the flight and wind-tunnel measurements are also included.

SYMBOLS

V airspeed, ft/sec

p rolling velocity, radians/sec

b wing span, ft

C_h hinge-moment coefficient based on projected-edge area of spoiler outboard of spoiler hinge axis and distance from spoiler hinge axis to centroid of that area, $\frac{H}{2qS_e d_e}$

c_w local wing chord used in defining spoiler deflection, ft

δ_s spoiler deflection, distance of spoiler tip from wing surface, ft

$\frac{pb}{2V}$ wing-tip helix angle, radians

H spoiler hinge moment, ft-lb

S_e projected-edge area of spoiler outboard of spoiler hinge axis, sq ft

d_e distance from centroid of projected-edge area to hinge axis of spoiler, ft

q dynamic pressure, lb/sq ft

M Mach number

α angle of attack, deg

INSTRUMENTATION

Standard NASA instrumentation was used in the flight program to measure control positions and forces, angular accelerations, rolling velocity, sideslip angle, airspeed, and altitude. Strain-gage installations were used to measure individual spoiler hinge moment and total hinge moment of the spoilers on the right wing.

The airspeed-nose-boom installation used in the present tests was the same as that used in reference 1 and measured airspeeds were corrected for position error in accordance with the calibration presented in reference 1.

EQUIPMENT

The test airplane was originally equipped with conventional internally sealed outboard-located flap-type ailerons which were modified to facilitate installation of the paddle-type spoilers. The modification consisted of removing the inboard halves of the ailerons and replacing them with fixed panels ahead of which the spoilers were located. The outboard halves of the original ailerons were retained and used for the normal flying phases of the flight tests.

Figure 1(a) is a photograph of the test airplane showing the paddle-spoiler installation in a fully deflected position for right roll. The spoilers on the left wing are deflected downward the same amount as those on the right wing are deflected upward. Figure 1(b) is a multiple-exposure picture showing the spoilers on the left wing deflected various amounts upward. It may be noted that even in the fully deflected position the spoilers overlapped one another and formed an unbroken barrier to the flow when viewed in the streamwise direction. The spoilers were staggered in a chordwise direction to avoid mechanical interference. This feature is shown clearly in figure 2. Also shown in figure 2 are the outboard locations of the spoiler hinges. The axes of rotation of the spoilers were positioned so that the front face of each spoiler was presented approximately normal to the local wind direction (disregarding induced-flow effects) over the full deflection range of $\pm45^{\circ}$ rotation about the spoiler hinge axes. Inasmuch as the spoiler axes of rotation were not perpendicular to either the front or the rear faces, the spoilers swept out conical surface segments during rotation rather than plane surfaces.

Two spoiler shapes were investigated in the flight tests. Both of these shapes had the same plan form, that is, the spoiler lengths outboard of the spoiler hinge axes were all about 2.4 times the average wing thickness at the location of the middle spoiler of the bank of five spoilers. The single exception to this rule was the inboard spoiler of each bank of five which was somewhat shorter. The two sets of spoilers differed in cross-sectional shape and bevel angle on the forward faces. Figure 3 defines these two shapes and includes all other dimensions pertinent to the geometry of the spoilers tested. Dimensions C and B in figure 3 correspond to wing thickness at the installed position of the spoilers. It may be noted that the actual thickness of one set of spoilers was equal to one-half of the projected-edge thickness and for reasons of convenience this set of spoilers is therefore designated as the "$\frac{1}{2}$ t" spoilers in the remainder of this report. Similarly, the other set of spoilers is referred to as the "$\frac{3}{4}$ t" spoilers.

The spoilers were situated at approximately the 70-percent-chord station (measured normal to the 25-percent-chord line) on the wings of the test airplane and covered the region from 52.9 percent semispan to 71.7 percent semispan. A line layout of the spoilers showing exact locations on the wing panels is given in figure 4.

The standard airplane control stick was used to drive both the modified flap-type ailerons and the spoilers. A variable-gear box controllable by the pilot in flight was incorporated into each control system. This feature allowed the pilot to select independently any desired ratio of aileron or spoiler control deflection per unit stick deflection from zero up to the maximum gains available. At maximum gain the full lateral stick throw of ±5.3 inches produced maximum aileron deflections of $\pm14^{\circ}$ and maximum spoiler rotations of $\pm45^{\circ}$. The variations of control deflection with stick deflection were essentially linear for both lateral-control systems. The original aileron booster which had a boost ratio of 37:1 was retained and used to drive the modified ailerons. The spoilers were actuated manually without benefit of power assistance of any kind.

The spoilers were constructed of aluminum honeycomb bonded to thin aluminum cover sheets. The front and rear spoiler faces were also riveted together along the edges of the spoilers. The spoilers were designed to withstand the predicted loads associated with full deflection at a Mach number of 0.95 at an altitude of 15,000 feet; these conditions defined the primary dynamic pressure limitation of the test airplane. Each spoiler was mass-balanced about its hinge axis in order to avoid spoiler flutter and no indications of spoiler flutter were noted during the flight tests.

Figure 5 is a two-view sketch of the test airplane. It may be noted that the spoilers were all located farther from the airplane center line than the tips of the horizontal tail. Therefore, the likelihood of encountering tail buffeting due to impingement on the horizontal tail of flow separated by the deflected spoilers was rather remote for the configuration tested.

Figure 6 presents the friction characteristics of the spoiler control system as measured on the ground. As may be noted, the friction forces are very large for a manually operated lateral-control system even though ballbearings were used at all rotating bearing points.

A 1/4-scale semispan wing model was used for the wind-tunnel tests. The semispan wing model had almost exactly the same plan form and thickness ratio as the wing on the test airplane. The airfoil section of the model wing was an NACA 65-012 section whereas the airplane wing had a modified symmetrical NACA 65-series airfoil section, 12 percent thick at the root and 11 percent thick at the tip. Six full-length spoilers, located between 52.9 percent and 71.7 percent of the wing semispan, were used on the model. The plan forms of the spoilers on the wind-tunnel model were geometrically similar to those on the test airplane and were located near the 70-percent-chord line.

METHOD

The characteristics of the paddle-type spoilers were evaluated in flight by making a series of abrupt rudder-fixed rolls at several speeds. Various magnitudes of lateral stick deflection both right and left were used at each speed. A chain stop was used to limit the stick deflection to the desired value. All the data presented in this paper were obtained at an altitude of 35,000 feet.

RESULTS AND DISCUSSION

The variation of wing-tip helix angle $pb/2V$ with spoiler deflection δ_s as obtained in flight at Mach numbers of 0.60 and 0.86 is presented in figure 7. Also presented in figure 7 are estimates of wing-tip helix angles based on the wind-tunnel measurements. When the wing-tip helix angle was estimated from the wind-tunnel data, the damping in roll was obtained from flight measurements presented in reference 2. Also, in order to make the flight and wind-tunnel measurements more directly comparable, the measured wind-tunnel rolling moments were multiplied by an area ratio factor of 0.807 to account for the fact that the wind-tunnel model had six full-length spoilers per panel and the airplane had only four full-length and one shortened spoiler per panel.

The agreement between the flight and wind-tunnel measurements is very good. The flight data show that no measurable change in steady rolling effectiveness occurred in going from a Mach number of 0.60 to 0.86. The maximum value of $pb/2V$ attained in flight is 0.055 at a Mach number of 0.86 at an altitude of 35,000 feet. Inasmuch as the paddle-spoiler system tested was considered to be a half-size installation (one-half the original aileron span was covered by spoilers), it appears that paddle-type spoilers have ample effectiveness for use as a primary lateral-control system on high-performance airplanes. Wind-tunnel data have shown that, when compared on the basis of projected area normal to the free-stream direction, paddle-type spoilers have about the same effectiveness as other commonly used spoilers located at this same position.

The data presented in figure 7 also show that the spoilers were ineffective (or possibly even had slight reverse effectiveness) at small deflections. This lack of spoiler effectiveness at small deflections might result from failure of the spoiler to cause a breakdown of the smooth flow or by leakage flow through the wing at the spoiler clearance gaps. A brief tuft study made during one flight and qualitative chordwise pressure distributions obtained during several flights indicated either or both reasons for the ineffectiveness might apply. In this connection it may be noted that some manufacturers have overcome the problem of low-deflection ineffectiveness of spoilers by using combinations of control types for the lateral-control system (that is, spoilers together with small flap-type ailerons).

The flight data presented in figure 7 are for the $\frac{1}{2}$ t spoiler. Rolling effectiveness data obtained with the $\frac{3}{4}$ t spoilers were essentially the same and are not presented.

The variation of hinge-moment coefficient with spoiler deflection as measured both in flight and in the wind tunnel are presented in figure 8. The hinge-moment coefficient presented is the average hinge-moment coefficient for one spoiler (obtained by dividing the total hinge moment resulting from deflecting all the spoilers by the number of spoilers). Actually, the individual spoiler hinge-moment characteristics varied considerably depending on position within a given bank of spoilers. Data are included for both the $\frac{1}{2}$ t and $\frac{3}{4}$ t spoiler configurations.

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The equivalent lateral stick forces associated with the hinge-moment data shown in figure 8 can be read from the extra ordinate scale included in the figure. These equivalent stick forces are presented rather than measured stick forces because high friction in the control system made any correlation between measured stick forces and aerodynamic hinge moments impracticable.

Inspection of figure 8 indicates considerable difference exists between the flight and wind-tunnel measurements of hinge moments. With either the $\frac{1}{2}$ t or $\frac{3}{4}$ t spoiler configurations the flight measurements indicate considerably more overbalance than do the wind-tunnel measurements. However, both the flight and wind-tunnel data exhibit the same trend (toward more overbalance) in going from the $\frac{1}{2}$ t to the $\frac{3}{4}$ t configuration. The apparent large difference between the flight and wind-tunnel curves is unduly emphasized by the sensitive ordinate scale. The flight curves are averages of data obtained from several flights because of the friction present in the control system. It is of interest to note that, with the standard ailerons on the test airplane, the actual aerodynamic hinge moments required to produce a given airplane rolling velocity were on the order of 10 times larger than those for the $\frac{1}{2}$ t paddle spoilers when flying at an indicated airspeed of 200 knots.

The wind-tunnel tests of this family of spoilers covered spoilers ranging from those with zero edge thickness to those with full edge thickness (no bevel on the forward faces). The hinge-moment characteristics obtained from the wind-tunnel tests varied from highly underbalanced for the zero edge thickness spoiler configuration to highly overbalanced for the 1.0t configuration and it was shown that edge thickness had a powerful influence on the hinge moments over the complete range of edge thicknesses tested. Extrapolating the flight data of figure 8 on the basis of the wind-tunnel trends appears to be permissible because of the agreement in trend and, if this is done, it would be predicted that, if flight tests of a set of $\frac{1}{4}$ t spoilers had been made, these spoilers would have shown approximately zero aerodynamic hinge moments for small to moderate spoiler deflections.

Flight measurements showing the effects of increasing the Mach number from 0.60 to 0.86 on the hinge moments of the paddle spoilers are presented in figure 9. These hinge-moment data are again the average hinge moments for one spoiler. The effect of increasing the Mach number is to cause about a 25-percent reduction in the hinge-moment coefficients.

As was mentioned previously, a large amount of mechanical friction was present in the paddle-spoiler lateral-control system. Figure 6 shows the variation of lateral stick force with lateral stick deflection as the stick was moved slowly on the ground. Near the neutral stick position, the stick force required to overcome the friction is about 10 pounds and, near the full stick deflection, the stick force required is about 20 pounds. The stick forces required to overcome the friction are of the same order of magnitude as the stick forces resulting from the aerodynamic hinge moment on the paddle spoilers. (See fig. 8.)

In the design and installation of the paddle-spoiler control system, considerable effort was made to keep the friction low. Ball bearings were used at all rotating bearing points. However, in order to resist the large bending moments arising from spoiler drag loads, it was necessary to use two relatively large ball bearings to support each of the 10 spoilers. Also, because of the large deflection range necessary with paddle spoilers ($\pm 45^{\circ}$ in the subject tests), the gear ratio between the stick and the spoilers was very unfavorable as compared with the gear ratios that are used with conventional ailerons which, for example, move only $\pm 15^{\circ}$ for full stick deflection. Both factors contributed to the unusually large stick friction forces in the subject installation as they would likely do in any other paddle-spoiler installation. In view of the likely high friction, even though the spoiler hinge moments could be made zero or slightly underbalanced (rather than overbalanced as in the present tests) the lateral-control force characteristics of a manual control system using paddle-type spoilers would probably be unsatisfactory to the pilot. However, based on the present limited investigation, the adoption of paddle-type spoilers should make possible the use of much smaller and less powerful power control units than are now required to drive conventional flap-type control surfaces. The main function of the power control system used with properly designed paddle-type spoilers would be to overcome the undesirable control system friction. Along with such a power control system an artificial feel system would in all probability be provided.

From a handling qualities standpoint the paddle-spoiler lateral-control system tested was unsatisfactory in some respects. The spoiler ineffectiveness at small deflections, together with the high friction and the overbalancing stick forces made it extremely difficult for the pilot to maintain wings-level flight. However, not all characteristics of the paddle-type spoilers tested were unfavorable. The pilot described the rolling performance for large spoiler deflections as smooth and pleasing and he was not able to detect lag in the build-up of rolling acceleration following abrupt control deflection. The yawing moments due to the combination of spoiler deflection and airplane rolling response were apparently very low because the pilot noted that he was able to make abrupt 360° rolls without incurring noticeable changes in airplane heading either during or after the roll. As noted previously, the spoilers were free of flutter tendencies for the conditions of speed and altitude tested. No tendency was noted for the spoiler installation to produce airplane buffeting when the spoilers were undeflected or were deflected moderate amounts. At full spoiler deflection, mild buffeting sometimes was noted by the pilot but even then it was not clear whether this buffeting was attributable to the spoilers or to wing stall which often occurs during rapid rolls at high airplane lift coefficients with normal aileron-control systems.

CONCLUSIONS

A limited investigation of a paddle-spoiler type of lateral-control system was made in flight using a swept-wing fighter airplane and in the Langley 300 MPH 7- by 10-foot tunnel using a semispan wing model. The results of this investigation lead to the following conclusions:

1. The effectiveness of the paddle-spoiler lateral-control system in providing roll was good for medium and large spoiler deflections but was essentially zero for small deflections. The flight and wind-tunnel measurements of rolling effectiveness were in very good agreement.

2. The aerodynamic hinge moments associated with the paddle-spoilers were small in comparison with those of flap-type controls. For the two spoiler shapes tested in flight the hinge moments were overbalanced. The wind-tunnel results showed that decreasing the paddle-spoiler edge thickness caused the hinge moment to change from overbalance to underbalance. This trend was also observed in the flight measurements.

3. The control-system friction forces for a paddle-spoiler lateral-control system are likely to be very high. Thus, even though the aerodynamic hinge moments of the spoilers are relatively small or even zero, it is likely that a power control with artificial feel would be required to make the pilot's control forces satisfactory. The power control unit, however, could probably be much smaller than is ordinarily required to drive flap-type controls.

4. The pilot thought that the rolling response of the paddle spoilers at large deflections was pleasingly smooth and free of lag and he was

favorably impressed by the lack of sideslip associated with rolling; however, the ineffectiveness of the spoilers at low deflections, the overbalance hinge moments, and the very large control-system friction of the spoiler installation tested were all unacceptable.

5. The paddle spoilers tested showed no indications of flutter and the buffeting attributable to them was mild or nonexistent.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., March 26, 1959.

REFERENCES

1. Thompson, Jim Rogers, Bray, Richard S., and Cooper, George E.: Flight Calibration of Four Airspeed Systems on a Swept-Wing Airplane at Mach Numbers up to 1.04 by the NACA Radar-Phototheodolite Method. NACA TN 3526, 1955. (Supersedes NACA RM A50H24.)

2. Triplett, William C., Brown, Stuart C., and Smith, G. Allen: The Dynamic-Response Characteristics of a 35° Swept-Wing Airplane As Determined From Flight Measurements. NACA Rep. 1250, 1955. (Supersedes NACA RM A51G27 by Triplett and Smith and RM A52I17 by Triplett and Brown.)

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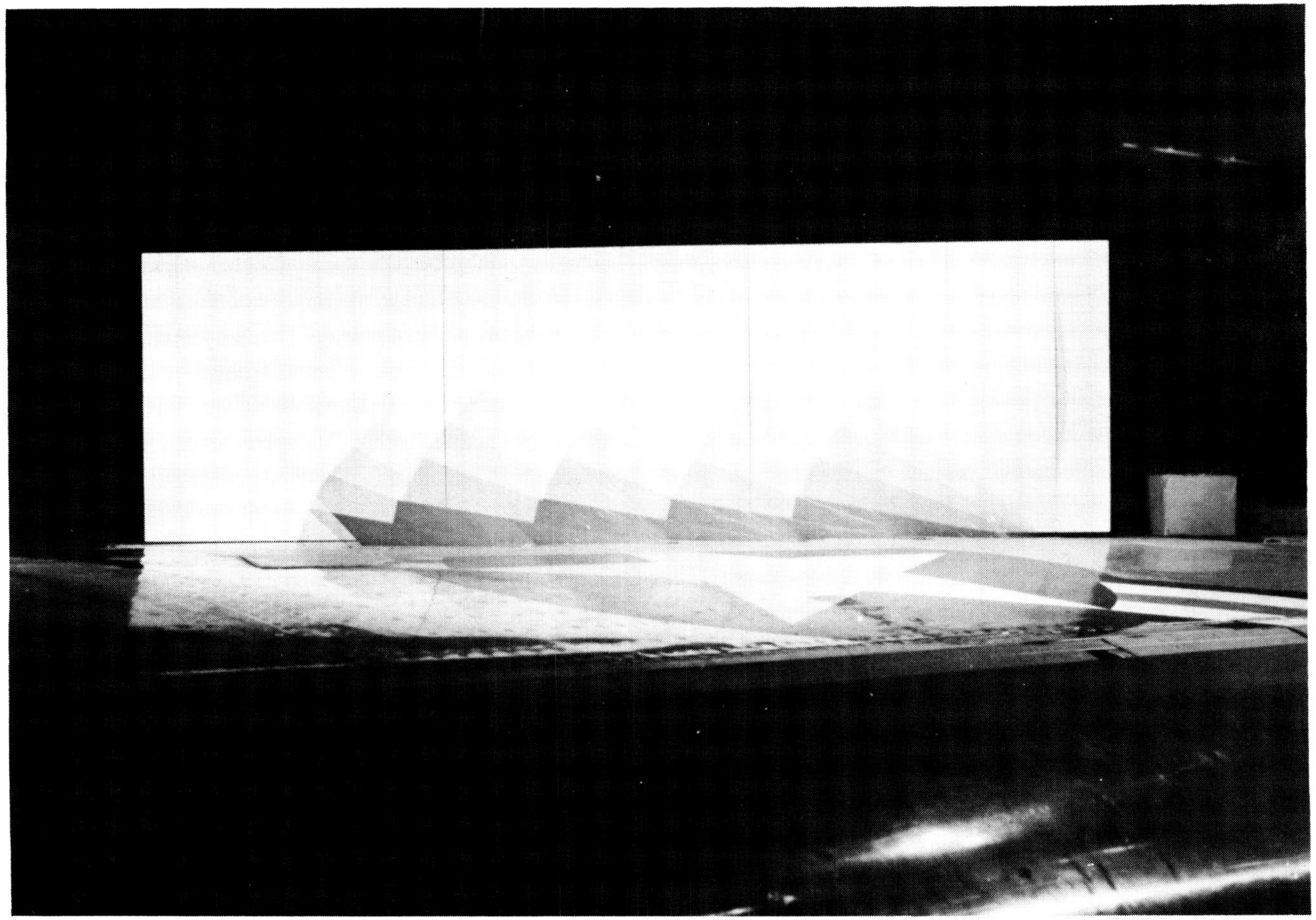
(a) A front view of the test airplane showing the paddle-type spoilers deflected fully to produce right roll.

Figure 1.- Photographs of test airplane.



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(b) Multiple-exposure picture cf spoilers on left wing deflected upward 10°, 20°, 30°, 40°, and 45° as viewed from the front along streamwise axis passing through the middle of the center spoiler. Grid of 1 inch square is positioned against rear of spoilers.

Figure 1.- Concluded.

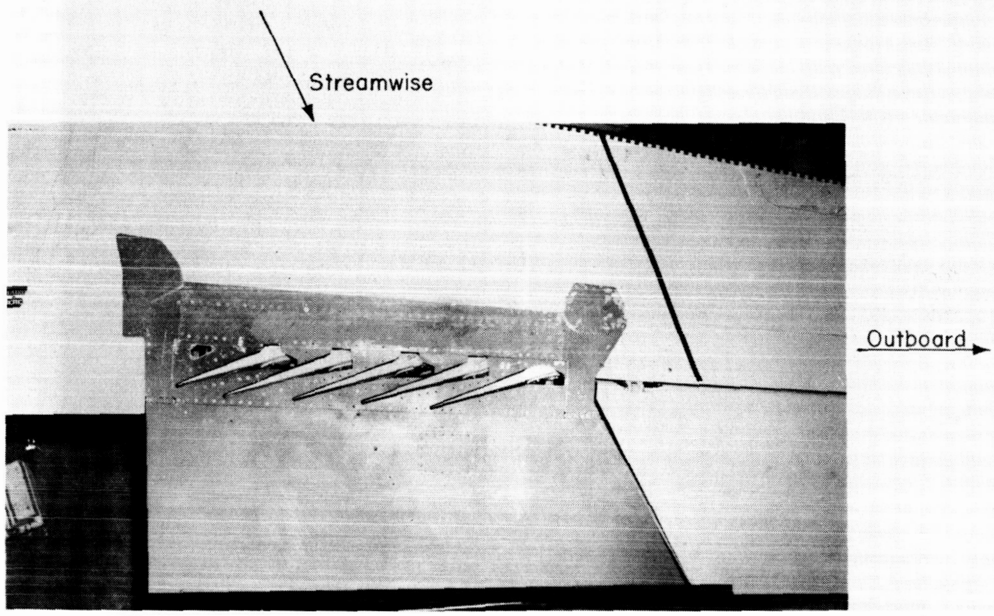

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Figure 2.- Top view of paddle-type spoiler installation in the right wing panel of the test airplane.

Spoiler No.	Dimension L	B	C	T
1	14.092	5.088	5.585	1.814
2	↓	5.241	5.737	↓
3	↓	5.384	5.889	↓
4	↓	5.527	6.040	↓
5	11.50	5.729	6.195	1.893

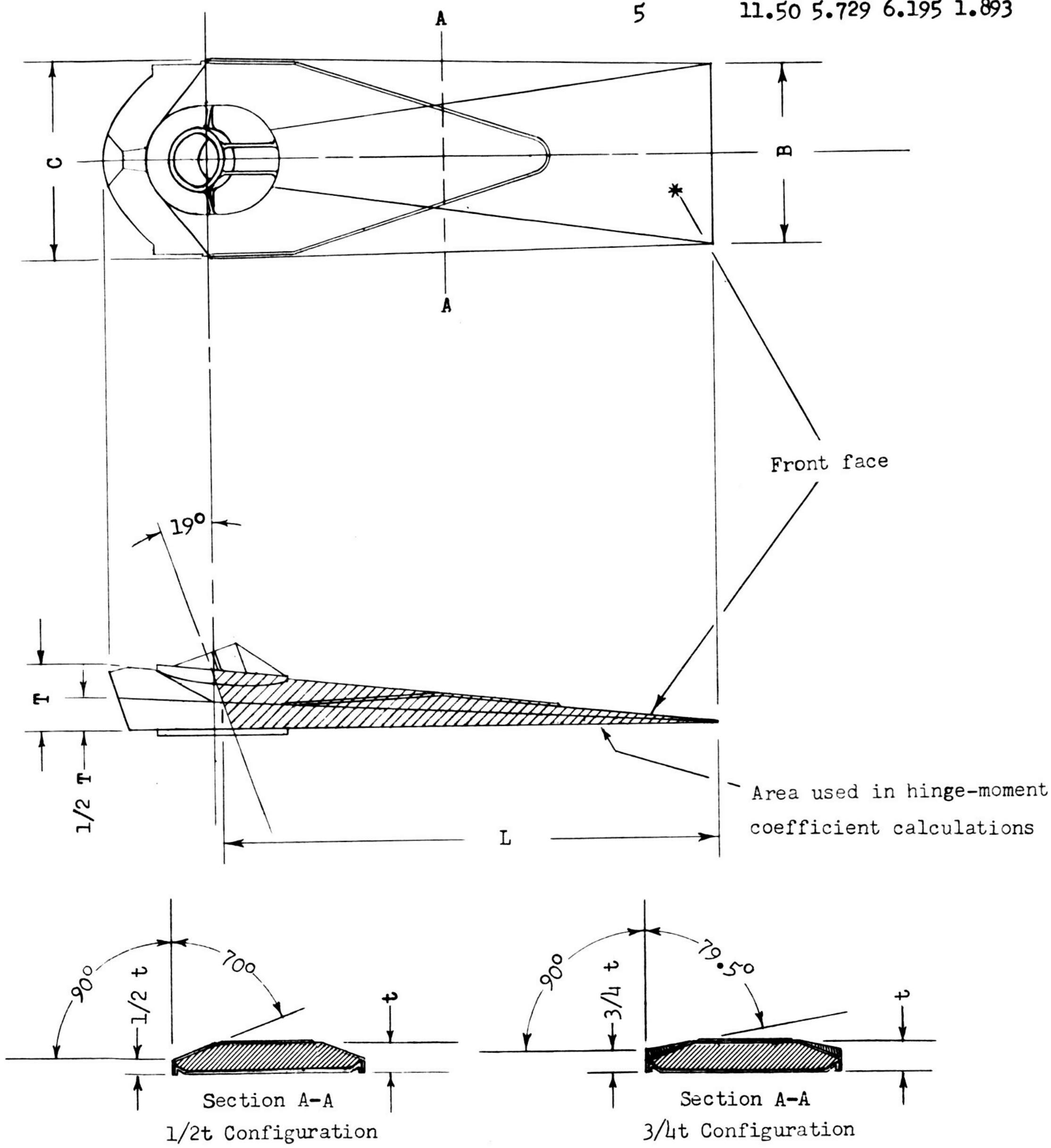

Figure 3.- A detailed sketch showing the dimensions of the paddle spoilers and indicating the two spoiler configurations used in the flight tests. All dimensions are in inches.

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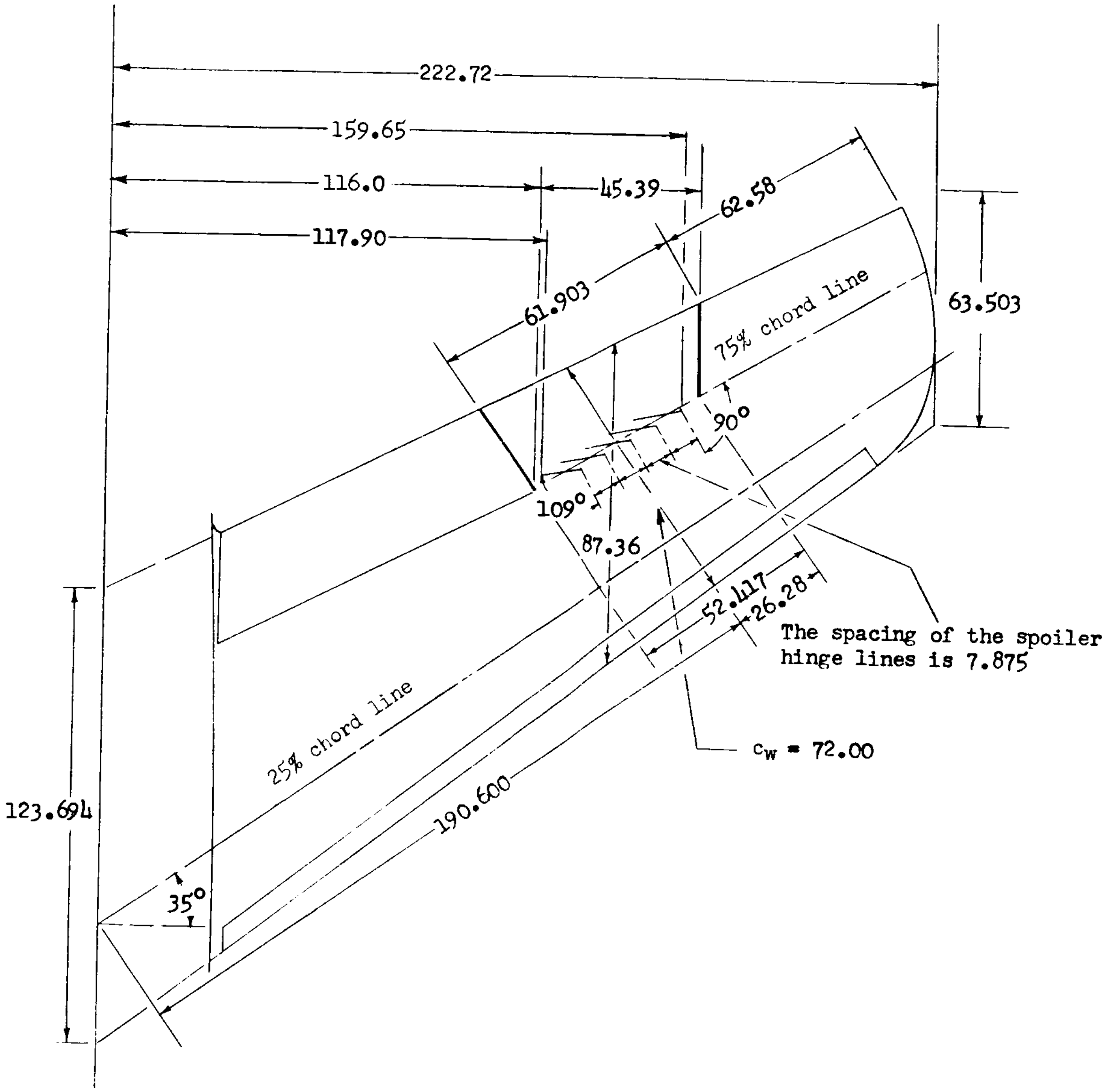

Figure 4.- A semispan plan-view sketch of the left wing showing the location of the paddle-type spoilers. All dimensions are in inches.

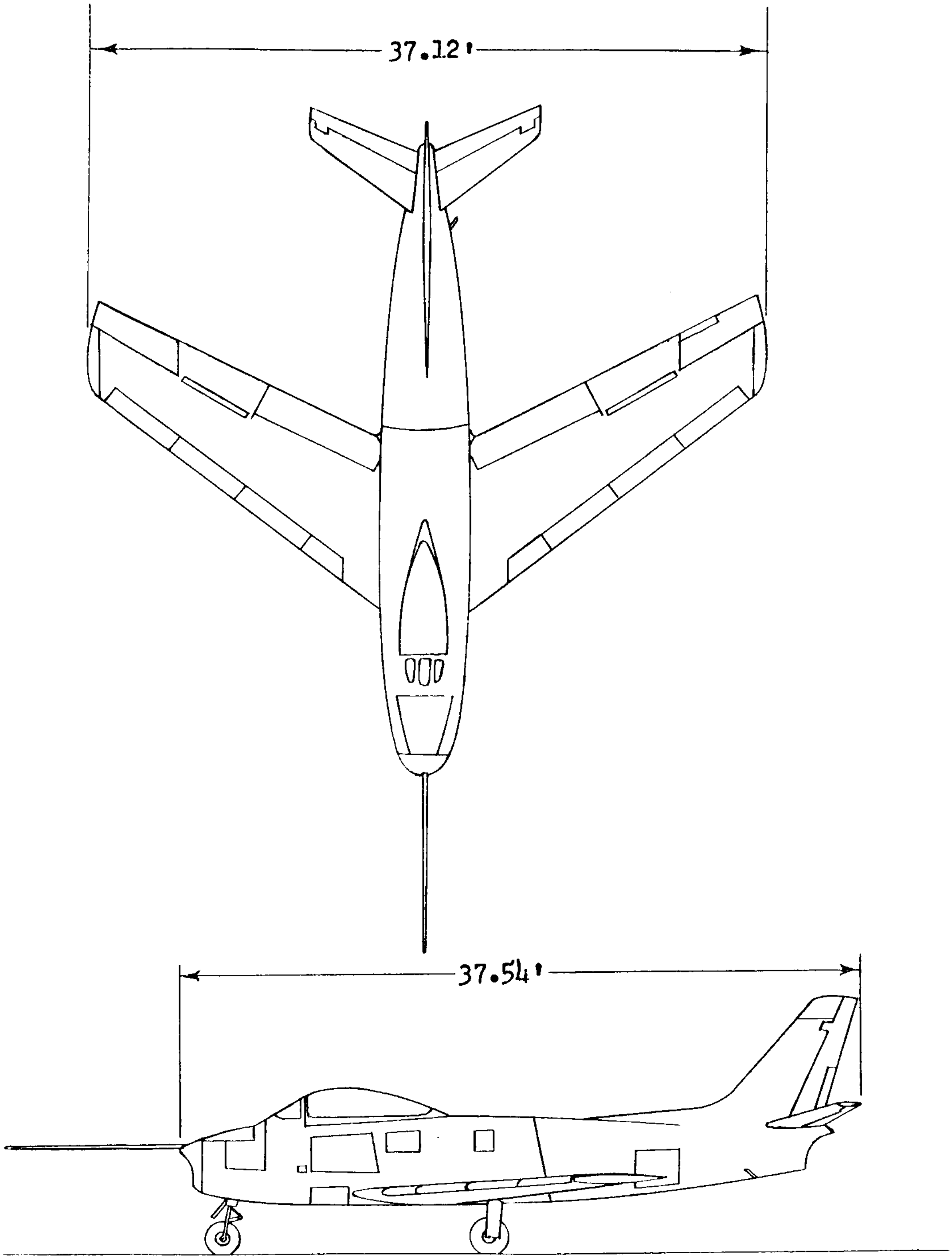

Figure 5.- Two-view sketch of the airplane used for the paddle-type spoiler installation.

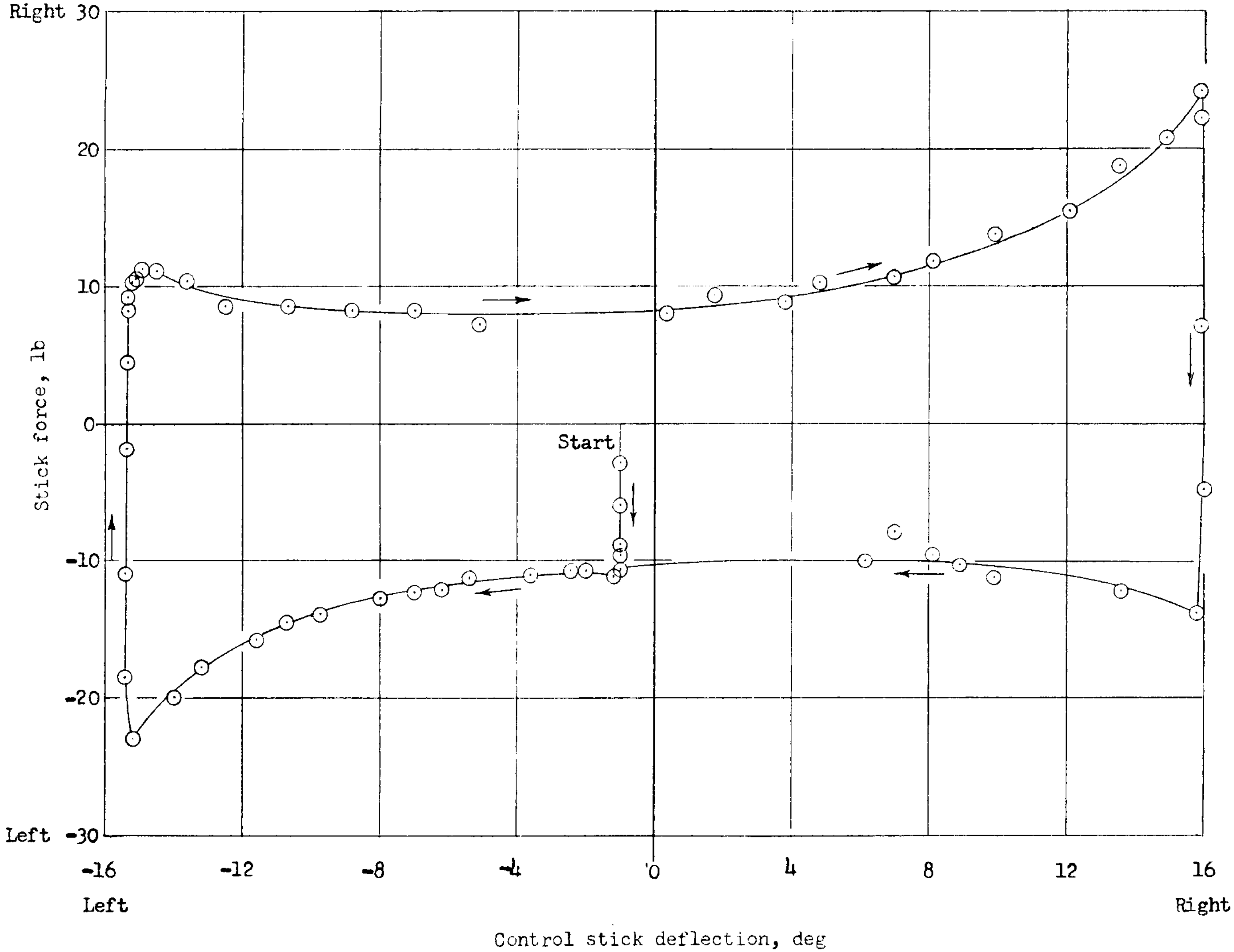

Figure 6.- Ground friction measurements for the paddle-type spoiler control system.

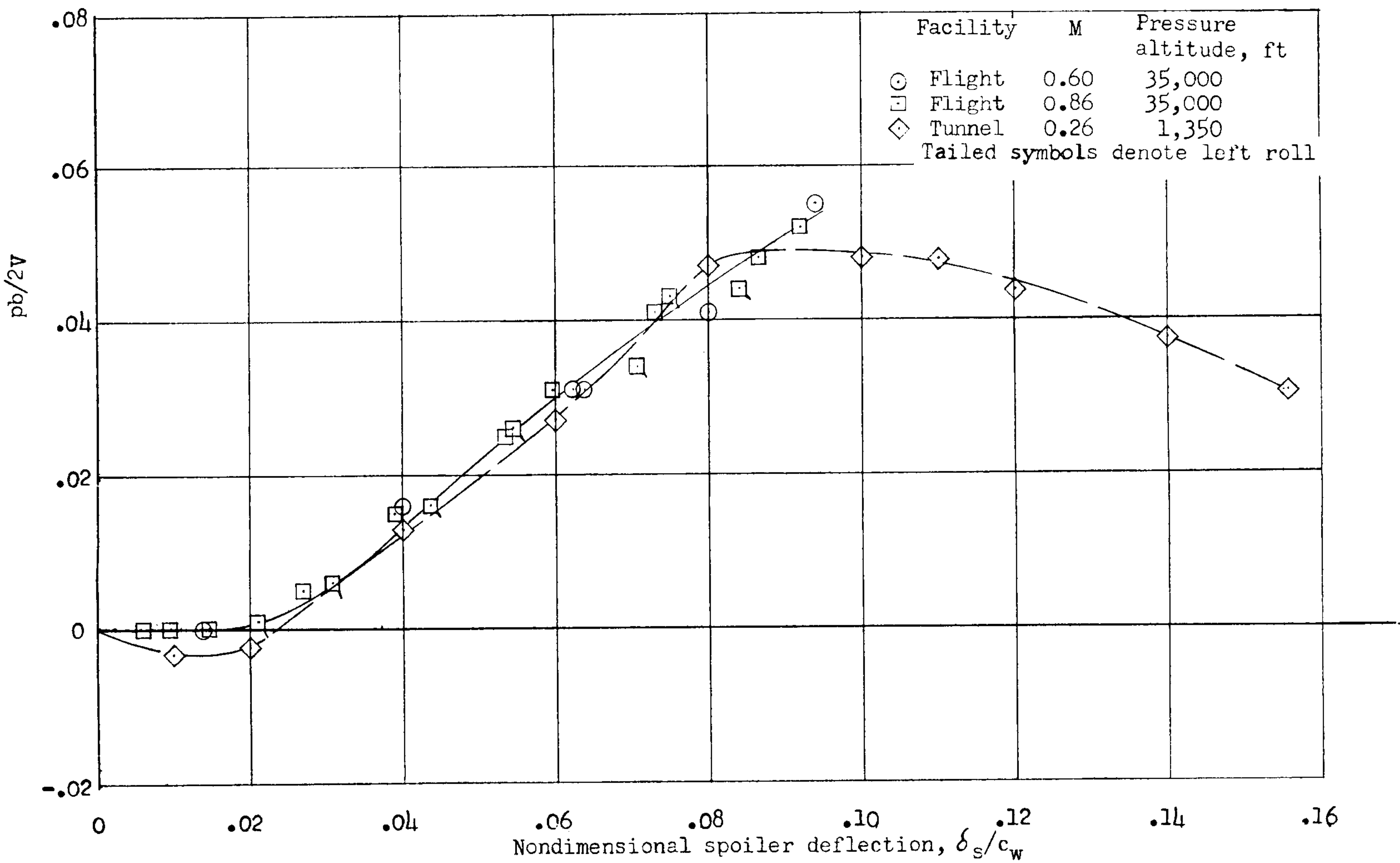

Figure 7.- A comparison between the flight and wind-tunnel variations of pb/2V with deflection for the paddle-type spoilers.

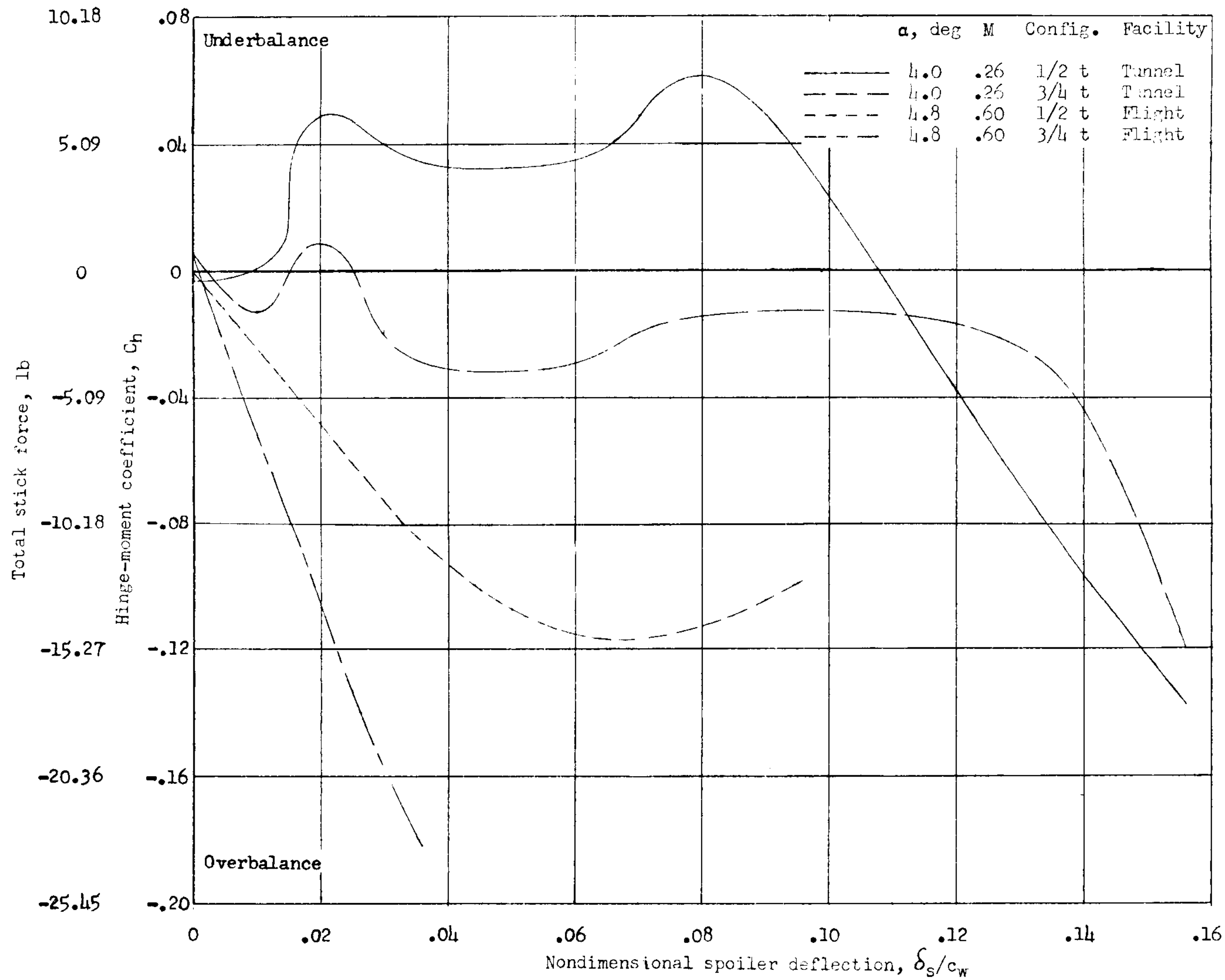

Figure 8.- Variations with spoiler deflection of average spoiler hinge-moment coefficient and of total stick force.

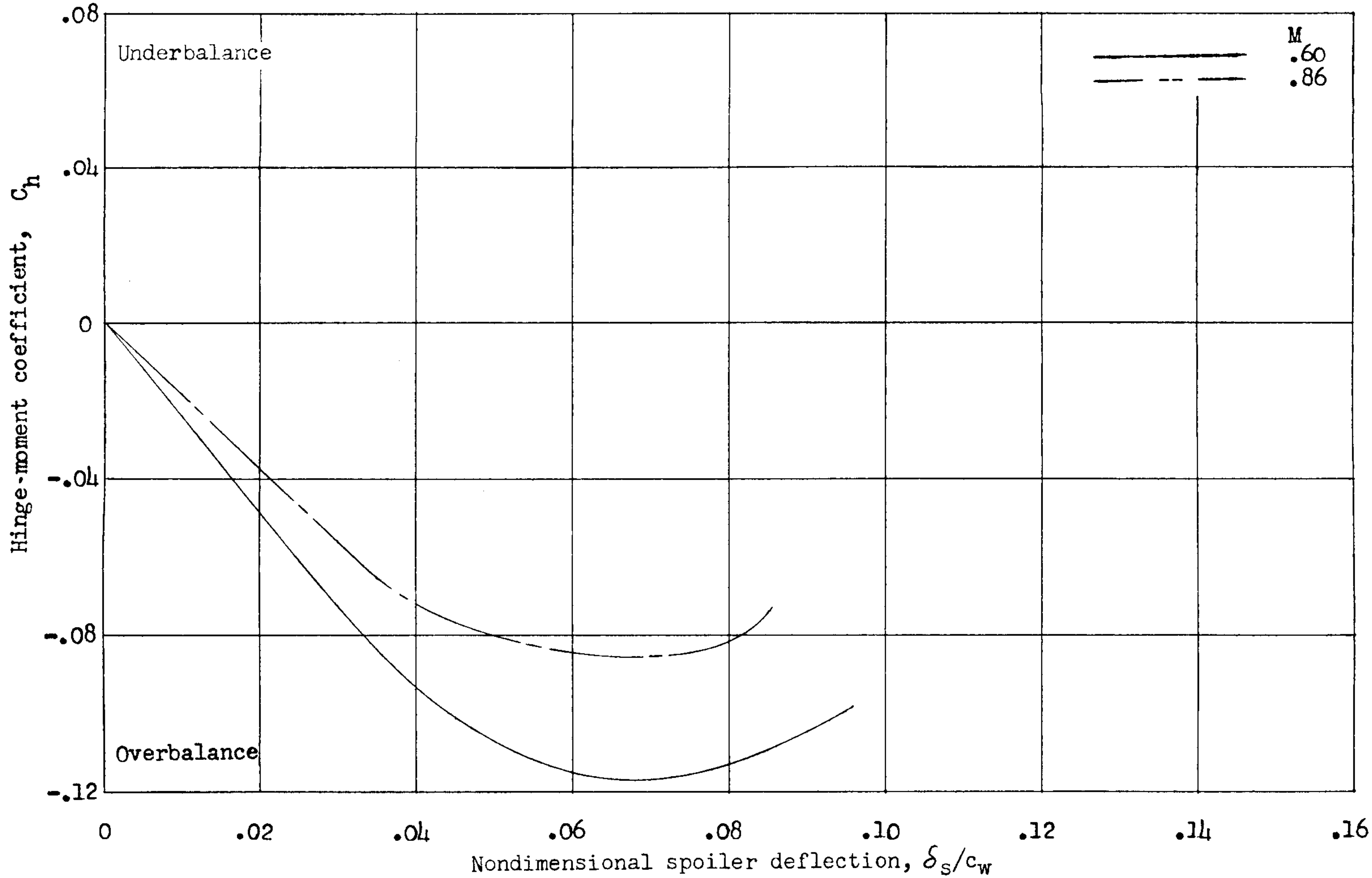

Figure 9.- The effect of increasing Mach number from 0.60 to 0.86 on the variation of average hinge-moment coefficient with deflection as measured in flight for the 1/2t spoiler.